with Al-free QWs in AlGaAs waveguides for laser diodes emitting at 800 nm," by Erbert *et al.* (herein "Erbert").

The rejections are substantially those from the Office Action of February 13, 2001 (Paper No. 7), the Examiner stating that Applicants' arguments of May 14, 2001 (Paper No. 8) are unpersuasive because the teachings of Erbert are not addressed. The Examiner additionally asserts that reducing residual carrier loss, as compared to the reduction of free carrier absorption taught by Gokhale, is an advantage that would naturally flow from following the suggestions of the prior art and cannot be the basis for patentability when the differences would be obvious.

Applicants respectfully traverse § 103(a) rejections for the reasons set forth below.

Regarding the Examiner's assertion that reducing residual carrier loss, as compared to the reduction of free carrier absorption taught by Gokhale, is an advantage that would naturally flow from following the suggestions of the prior art, the Gokhale article merely discloses that the reduction of transmission loss is effected by reducing the overlap of the optical mode with the highly doped cladding regions of InGaP. Further, in view of the fact that the loss also depends on the quality of the crystals, Gokhale merely discloses data, on the basis of which the above observation about the Gokhale article is justified.

On the other hand, Applicants have found in experiments, in which the number of quantum wells is changed from 1 to 4 under the substantially constant light distribution in the combination of an active layer of InGaAsP with a cladding layer of AlGaAs, that transmission loss is substantially constant, *i.e.*, 2 cm^{-1} per one quantum well, and increases in proportion to the number of quantum wells, and that the loss in the semiconductor laser <u>is mainly governed by loss</u>

by the quantum wells themselves. This shows that the loss due to the overlap of the optical mode with the cladding layer is substantially neglectable compared with that due to the quantum wells.

Further, as shown in Fig. 14, the Applicants have found in experiments, in which the thickness of the optical waveguide layer was changed under the same parameter (the loss is 2 cm^{-1} per one quantum well) as Fig. 13, and the number of quantum wells is 1 or 2, that the loss is determined by the ratio of the overlap of the laser light with the quantum well layer.

Therefore, the Gokhale reference teaches away from these conclusions regarding loss, such that the associated benefits would not flow from the teachings of Gokhale, since there would be no recognition of how to design the laser structure to minimize these losses.

Further, the Applicants have found in the above mentioned experiments that the use of a cladding layer including Al and an active layer made of InGaAsP would provide the same characteristic of the loss as that of all Al-free lasers.

The cause of the overall transmission loss of a laser depends on the structure of the semiconductor diode element to be used. This is clear from the differences between the present invention and Gokhale regarding the causes of the loss of the laser.

Therefore, Applicants submit that the Examiner's assertion that reducing residual carrier loss, as compared to the reduction of free carrier absorption taught by Gokhale, is an advantage that would naturally flow from following the suggestions taught in the prior art is incorrect.

Additionally, the Examiner states that "Erbert teaches the structure of Al-Free QW's in AlGaAs waveguides . . . in order to reduce degradation of lasers containing Aluminum in the

active region. In addition, it is well known in the art of lasers that a lower cladding is used to further absorb unwanted emissions of the QW region and further confine the laser guided within the waveguide structure. Therefore it would have been obvious to someone of ordinary skill in the art of semiconductor lasers at the time of the invention to use AlGaAs as an upper and lower cladding layer to conform with conventional practice while making the QW free of Al to decrease the rate of laser degradation." Paper No. 11, paragraph bridging pages 3-4.

Regarding Erbert, Applicants did discuss the use of AlGaAs cladding layers, which the Examiner proposed to get from Erbert, in the Amendment of February 13, 2001 (Paper No. 8):

> "Applicants submit that substituting AlGaAs for the InP cladding layer of Fiddyment "to absorb unwanted emissions of the QW region and further confine the laser guided within the waveguide structure" is not suggested by the applied art. Specifically, Gokhale teaches to reduce the overlap of the optical mode with the cladding layer, to reduce free-carrier absorption in the cladding layer, and to decrease confinement, by widening the optical waveguide layers. *See* Gokhale page 226, column 2. Waveguide broadening decreases the confinement factors of the laser mode in the cladding layers, thereby reducing losses. *See* Gokhale page 2267, column 2 to 2268, column 1, and Fig. 2(a) and 2(b). Fiddyment forms the device utilizing an etching method that relies on the etching of the InP layer 7, "without appreciably attacking quaternary layer 5". *See* Fiddyment column 6, lines 50-57. If, as the Examiner suggests, AlGaAs is substitute for InP, it is uncertain from the teachings of the applied references as to whether the etching method and/or structure of Fiddyment would have to be further modified. Any such uncertainties should be construed against the Examiner. Moreover, in view of the teachings of Gokhale regarding the widening of the optical waveguide layers, which the Examiner relies upon to support widening the optical waveguide layers of Fiddyment, there would be no motivation to substitute AlGaAs as the cladding layers to absorb unwanted emissions." Paper No. 8, page 7.

Applicants submit the following comments to supplement the argument from Paper No. 8.

Erbert teaches Al-free active regions "embeded in an AlGaAs-waveguide structure." *See* Erbert, page 46, end of paragraph 2, and Fig. 1. As the Examiner states, Erbert does suggest that Al in the active region is a "potential source of degradation." *See* Erbert, page 46, middle of paragraph 2. Erbert states that "[u]sing an AlGaAs-waveguide the leakage currents are reduced probably due to the higher band-offsets in the conduction band between the QWs and the AlGaAs barriers in comparison to quaternary ones." *See* Erbert, page 46, middle of paragraph 5.

However, these teachings are <u>irrelevant</u>, as one skilled in the art would not swap the InP cladding layer of Fiddyment with AlGaAs. The Examiner has not addressed the argument from Paper No. 8, that substituting AlGaAs for the InP of Fiddyment results in uncertainties as to whether the etching method and/or structure of Fiddyment would have to be modified. The InP is important to the teachings of Fiddyment, as the etching characteristics of the material, in comparison to the waveguide materials, are essential to the creation of the semiconductor structure. Such uncertainties about the viability of the combination should be construed against the Examiner. Without a showing that such a substitution is possible in the invention of Fiddyment, the Examiner's rationale is improper. *See* MPEP § 2145.

Moreover, while Erbert suggests benefits to having a waveguide layer which includes aluminum, Erbert explains no specific benefit to having aluminum in the cladding layers (*i.e.,* p- and n-AlGaAs layers, *see* Fig. 1). Applicants interpret the Examiner's argument to imply that since "it is well known in the art of lasers that a lower cladding is used to further absorb unwanted emissions of the QW region and further confine the laser guided within the waveguide structure," that the benefits taught for Al waveguide layers by Erbert would also benefit the cladding layers.

However, if broadening the optical waveguide layers of Fiddyment to meet the claimed 0.25 μm limitation is suggested by Gokhale, as the Examiner asserts, then the reasoning for this broadening must be considered. Gokhale teaches that broadening "decreases the confinement factors of the laser mode in the cladding and QW layers and therefore decreases the internal loss..." *See* Gokhale, page 2267, bottom paragraph of right column. This broadening is to "lower free-carrier absorption" and "improve external differential efficiency" by reducing the overlap of the optical mode with the higher doped cladding regions. *See* Gokhale, abstract and page 2266, column 2. A consideration is the choice of materials for the cladding. *See, e.g.,* Gokhale, page 2267, column 1.

One example of why the choice of materials is important is the free carrier absorption. Free carrier absorption, as is known in the art, is affected by wavelength and material. *See* attached excerpt from Guided-Wave Optoelectronics by Tamir (Ed.). As illustrated in Gokhale (*see, e.g.,* page 2266, "Introduction"), Erbert (*see, e.g.,* the title), and Fiddyment (*see* column 1, lines 43-46), aluminum-based materials are used in devices operating in the range of 0.8-0.98μm. However, Fiddyment, which uses InP cladding, is operating in the range of 1.3 to 1.6μm. *See* column 1, line 29-30, Figure 9.

If one skilled in the art were trying to modify Fiddyment in view of the teachings of Gokhale and Erbert, and seeking "an upper and lower cladding layer to *conform with conventional practice*" as the Examiner asserts, they would logically choose materials that are "conventional practice" for the wavelength they are operating at, rather than choosing a material conventionally used for a different wavelength. Thus, in view of the teachings of Gokhale, there

is suggestion away from using the AlGaAs of Erbert for the cladding layers of the device of Fiddyment, as AlGaAs has not been shown by the Examiner to be "conventional" at the wavelength taught in Fiddyment.

Applicants assert that claims 2, 4, and 5 are also patentable, at least as further limitations on independent claim 1, for the reasons offered above.

Further, the Examiner asserts, regarding claims 5 and 6, that "optimization within the prior art conditions or through routine experimentation is not inventive. MPEP § 2144.05. Here, the Applicant has optimized the thicknesses of the waveguide layers and cladding layers as disclosed and taught by the prior art as discussed above." Paper No. 11, page 4, paragraph 3.

"A particular parameter must first be recognized as a result-effective variable, i.e., a variable which achieves a recognized result, before the determination of the optimum or workable ranges of said variable might be characterized as routine experimentation." MPEP § 2144.05(II)(B).

Regarding claim 5, there is nothing in the applied art to suggest recognition of an advantage to asymmetrically thick optical waveguide layers, as the applied art employs symmetric waveguide layers. As taught in the present specification, using different thicknesses shifts the quantum well layer "from a position in which the light intensity is maximized and the optical confinement factor Γ is reduced, and accordingly, the light density in the quantum well can be reduced when the thicket one of the optical waveguide layers is not smaller than 0.25 μm." Page 26, line 26 to page 27, line 8.

Further, regarding claim 6, Fiddyment teaches that "[f]or the confining effect to be substantial in optical devices, the first elevated semiconductor portion is likely to have a width of not more than about 15 μm ... [u]sually the width will be at least 1 μm, commonly 2 μm or more." *See* column 3, lines 50-54. Therefore, Fiddyment did attribute an importance to the thickness of the cladding layer.

In view of the above, reconsideration and allowance of this application are now believed to be in order, and such actions are hereby solicited. If any points remain in issue which the Examiner feels may be best resolved through a personal or telephone interview, the Examiner is kindly requested to contact the undersigned at the telephone number listed below.

Applicant hereby petitions for any extension of time which may be required to maintain the pendency of this case, and any required fee, except for the Issue Fee, for such extension is to be charged to Deposit Account No. 19-4880.

Respectfully submitted,

David A. Klein

David A. Klein
Registration No. 46,835

SUGHRUE MION, PLLC
2100 Pennsylvania Avenue, N.W.
Washington, D.C. 20037-3213
Telephone: (202) 293-7060
Facsimile: (202) 293-7860

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Theodor Tamir, Ph. D.
Polytechnic University, 333 Jay Street, Brooklyn, NY 11201, USA

Series Editors:
Dr. David H. Auston
Columbia University, Dept. of Electrical Engineering, New York, NY 10027, USA

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Institut für Theoretische Elektrotechnik, Rhein.-Westf. Technische Hochschule, Templergraben 55, D-5100 Aachen, Fed. Rep. of Germany

Professor Takuo Sugano
Department of Electronic Engineering, The Faculty of Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, 113, Japan

Managing Editor: Dr. Helmut K. V. Lotsch
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Theodor Tamir (Ed.)

Guided-Wave Optoelectronics

With Contributions by
R. C. Alferness W. K. Burns J. P. Donnelly
I. P. Kaminow H. Kogelnik F. J. Leonberger
A. F. Milton T. Tamir R. S. Tucker

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reverse traveling wave, as shown in Fig. 6.15. The length of the perturbation region determines the amount of light transmitted and reflected.

If the grating has vertical side walls, it can be treated as a series of alternating waveguide sections of widths a and b which have slightly different mode shapes and different phase velocities, β_1 and β_2 respectively. A reflection occurs at each boundary and if the reflections constructively interfere a large reverse traveling wave can build up. Constructive interference of the reflected waves occurs if

$$\beta_1 a = \beta_2 b = (2m-1)\tfrac{\pi}{2} \tag{6.1.11}$$

where $m = 1, 2, 3, \ldots$. For a small perturbation, the period of the grating is related to the average propagation constant $\beta_0 = (\beta_1 + \beta_2)/2$ and is given by

$$\Omega = a + b = \frac{m\pi}{\beta_0} = \frac{m\lambda}{2n} \tag{6.1.12}$$

Gratings with periods of a multiple of $\frac{\pi}{\beta_0}$ are generally used in AlGaAs/GaAs DFB and DBR lasers since the fundamental period in the III-V semiconductors is about 1200 Å for $\lambda = 0.8\,\mu$m.

c) TE to TM Mode Coupling. If the index of refraction in the waveguide is anisotropic, coupling between TE and TM modes can occur whenever two principal axes of the index ellipsoid do not lie in the plane of the waveguide. The index of refraction in the III-V and II-VI semiconductors is nominally isotropic but can be made anisotropic by the application of either an electric field or built-in strain. Strain effects have been previously described and electro-optic effects will be discussed in Sect. 6.4.

6.1.5 Optical Loss

Losses in semiconductor waveguides are due primarily to either scattering into radiation modes or absorption. In addition, radiation losses can occur at transitions and in curved sections. Roughness at waveguide boundaries can lead to scattering losses. This could be one reason why guides grown by LPE typically exhibit higher losses than those grown by vapor-phase techniques. These scattering losses are generally higher at boundaries where the refractive index change is large. Deeply etched semiconductor rib guides are especially prone to scattering loss because of the large index difference at the semiconductor-air interface. Smooth side walls are therefore important in these structures. The side-wall shape of these guides can be controlled using ion-beam-etching techniques, but these techniques generally faithfully reproduce roughness in the edges of the etch mask. Chemical etching tends to smooth side-wall roughness, but the side-wall shape tends to be deter-

mined by crystallographic directions. Scattering can also occur from imperfections, such as precipitates, metal inclusions and other defects in the semiconductor layers.

Various types of absorption can occur in the different semiconductor layers comprising the waveguide. Free-carrier absorption [6.1] is an important loss mechanism in n^+ and p^+ material and can place a lower limit on the losses in n/n^+ homojunction waveguides. Free carriers not only reduce the real part of the dielectric constant, but also increase the absorption of the semiconductor. The free-carrier absorption can be calculated along with changes in the real part of the dielectric constant and is given approximately by

$$\alpha = \frac{g e^3 \lambda_o^2 N_c}{4\pi^2 m^{*2} \mu c^3 n \varepsilon_o} \tag{6.1.13}$$

where μ is the mobility and g is a factor which depends on how the carrier scattering time is related to its energy and is usually slightly larger than one for acoustic lattice scattering and around three for ionized impurity scattering. The other parameters have been previously defined. The free-carrier absorption is proportional to the number of free carriers N_c, to the square of the free-space wavelength and inversely proportional to the carrier mobility. The λ_o^2 dependence of the free-carrier absorption has been found to be only approximately true, probably due to variations in the g factor with wavelength. Losses at $1.3\,\mu$m in n^+-GaAs ($n \sim 1$–$2 \times 10^{18}\,\mathrm{cm}^{-3}$) are usually > 10–$20\,\mathrm{cm}^{-1}$ (43–86 dB/cm). Minimum losses in a single-mode homojunction slab waveguide due to the n^+-substrate ($10^{18}\,\mathrm{cm}^{-3}$) are expected to be on the order of $0.6\,\mathrm{cm}^{-1}$ (2.5 dB/cm).

Interband free-carrier absorption, i.e., absorption due to a transition between electrons in a Γ minimum and a higher conduction band, are also possible and have been observed in n^+-InP. In p^+ material, absorption can also occur between the light- and heavy-hole valence bands, adding to the effects of carrier concentrations on absorption coefficient.

Below-bandgap absorption can also occur due to deep levels in the band gap. Figure 6.16 illustrates the absorption coefficient vs. wavelength in n-type InP with several different impurity concentrations [6.61]. As the wavelength approaches the band gap, absorption increases rapidly due to band tailing, exciton absorption, acceptor-donor absorption, etc. The Burstein shift, i.e., band filling, is responsible for the absorption decrease with increasing carrier concentrations for energies greater than the band-gap energy. Electric fields affect this near-band-edge region via the Franz-Keldysh or electroabsorption effect (Sect. 6.4). Below the band-edge, the absorption decreases to a minimum and then increases due to free-carrier absorption. The minimum reached will depend on band tailing, free-carrier interband absorption, deep levels, etc. For InP, the local minimum below the band edge is due to absorption from electrons being excited from the Γ mini-

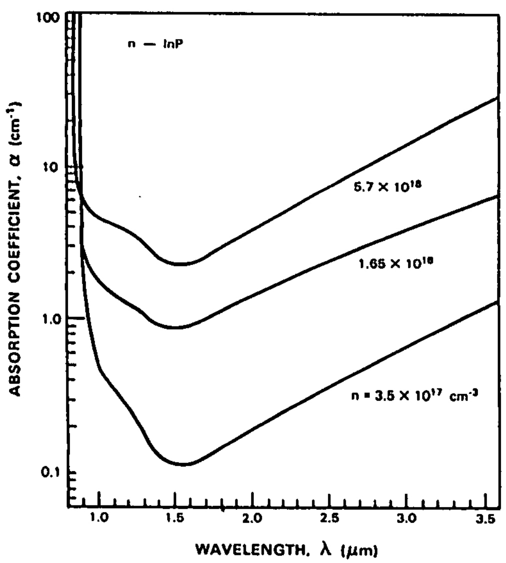

Fig. 6.16. Optical absorption vs. wavelength for n-type InP samples with different impurity concentrations [6.61]

mum to an L minimum. For low loss, waveguides should be fabricated in low-carrier-concentration material and operated below the band edge. In general, this minimum loss occurs about 0.5 μm from the band edge for $\sim$ 1-μm band-gap materials. For devices relying on the electroabsorption or a nonlinear band-edge effect, however, operation near the band edge may be necessary.

In waveguides containing quantum wells or superlattices, additional absorption due to the quantized conduction and valence band levels are possible. An easily saturable exciton absorption, which is electric-field dependent, is also present in these structures and may be useful for some nonlinear optical effects.

A useful way to estimate the absorption loss α in guides is from the expression

$$\alpha = \sum_{i=1}^{3} \alpha_i P_i / P_{\mathrm{T}} \quad . \tag{6.1.14}$$

Here α_i and P_i are the absorption coefficient and the power carried in each of the guide layers (e.g., core, cladding) and P_{T} is the total power in the guided mode. For example, one can see that losses in heterojunction guides can be inherently lower than those in the homojunction guides for comparable low-loss core layers, since the wider-band-gap cladding of the heterojunction will have lower absorption than a heavily doped homojunction substrate.

Losses in semiconductor channel waveguides are often determined by measuring the transmission through several different lengths of the same

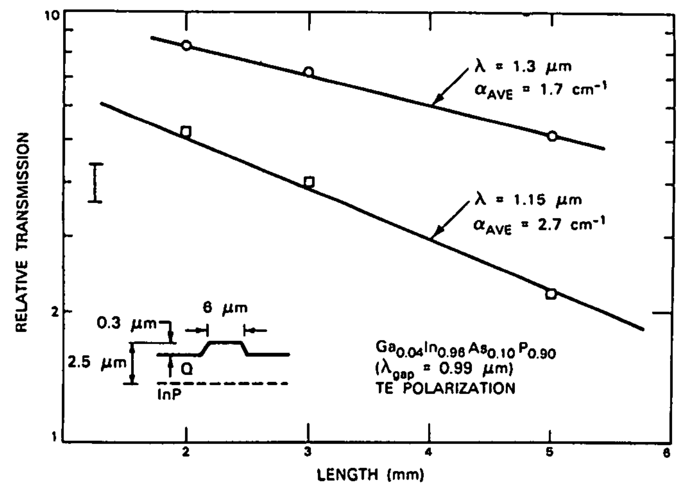

Fig. 6.17. The relative transmission at 1.15 and 1.3 μm vs. sample length for rib GaInAsP/InP waveguides obtained using end-fire coupling. Waveguide loss is obtained from the slope of the data [6.94]

sample using an end-fire coupling technique. The transmission is plotted as a function of length, as illustrated in Fig. 6.17 for data obtained on some GaInAsP/InP waveguides at 1.15 and 1.3 μm, and the loss obtained from the slope of the data. Although this technique is usually satisfactory when losses are $\gtrsim 0.5\,\mathrm{cm}^{-1}$ (2 dB/cm), variations in the quality of the cleaved faces as the sample is shortened and the existence of Fabry-Perot modes between the two end faces made it difficult to reproducibly measure very low losses using this technique. It has recently been reported that small changes in sample temperature can be used to change the index and length of the guides and therefore the effective length of the Fabry-Perot cavity [6.62]. By measuring the maxima and minima in the transmission, the losses can be determined without cleaving the sample to different lengths. The same effect can also be obtained by tuning the wavelength of the laser used in the measurements.

Loss has also been determined by measuring the light scattered out of the top surface due to imperfections in the waveguide as a function of distance. The technique is usually only suitable where the losses are high. Raman scattering has also been used to measure loss in GaAs/AlGaAs waveguides [6.63].

6.1.6 Curvature Loss

The ability to change direction on a waveguide chip is limited by mode conversion to radiation modes (assuming single-mode operation). Due to the optical confinement properties in which the optical fields decay outside of